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Research proposal on modeling the ice-structure interaction between wave energy converters and ice ridges

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Frontpage

Modeling the ice-structure interaction between wave energy converters and ice ridges.

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Summary

This is a thesis preparation for research that focuses on investigating the interaction between point absorber-type wave energy converters (WEC's) and ice ridges in cold climate environments. Wave energy is a renewable energy source with a potential to grow as large institutions such as the European Union want to increase the amount of ocean energy. Potential locations for wave energy farms include seas where sea ice is present. However, there is still a lot unknown about how wave energy converters perform in ice-prone environments. There has been research done on the interaction between WEC's and level-ice, but the research on ice-structure interactions between WEC's and ice ridges has so far been extremely limited, even though this is likely to be a determining factor in ice-prone areas. This research tries to improve the knowledge in that area.

The main objective is to model a collision between a point absorber and an ice ridge. This will be achieved by focusing on the other objectives such as identifying and quantifying the primary forces involved, developing a 3D computational model, determining critical ice ridge threshold sizes, and evaluating mitigation strategies for point absorbers against ice ridges. The research aims to answer the question what the potential impacts for point absorber-type wave energy converters are when colliding with ice ridges.

1 Introduction

1.1 Research context

One of the ways to harvest renewable energy is by using a wave energy converter, shortened as WEC. Currently there are several different concepts for WEC's. They have already been deployed in several regions of the world and there are also plans for future development. For example, the European Union aims to have installed at least 1 GW of ocean energy by 2030 and 40 GW by 2050 [1].

1.2 Research problem

Wave energy converters show potential for deployment in ice-prone seas, increasing their geographical applicability. There have been studies done on the impact of level ice on WEC's [2], however this is often not the critical calculation factor in in-prone regions. Ice ridges are expected to be the more leading force, which so far has not been covered in WEC research. The extremely limited amount of research on the effects of ice ridges on WEC's represents a crucial gap of knowledge for the applicability of WEC's in ice-prone regions.

1.3 Research objective

The objective of this thesis is to model the effect of ice-ridges on WEC's, specifically for point absorbers. Underneath the objectives are described, it comes down to modeling the collision between a point-absorber type wave energy converter and an ice ridge.

List of research objectives

- To identify and quantify the primary forces acting during the interaction between a point absorber-type WEC and an ice ridge, including hydrodynamic, ice-induced, and structural response forces.
- To develop a model that simulates the interaction between a point absorber-type WEC and an average-sized ice ridge for a better understanding of what happens during a collision.
- To determine the critical size thresholds of ice ridges at which point absorber wave energy converters are likely to experience structural failure or operational disruption.
- To evaluate the effectiveness of various mitigation strategies designed to protect point absorber wave energy converters from damage caused by ice ridge interactions in cold climate marine environments.

1.4 Research scope

This research aims to investigate the interactions at play between a point absorber-type wave energy converter and ice ridges in cold climate environments. The scope includes

- Identification and quantification of key forces (hydrodynamic, ice-induced, and structural response) during point absorber WEC-ice ridge interactions.
- Development of a 3-dimensional computational model simulating the interaction between a point absorber and an average-sized ice ridge.
- Determination of critical ice ridge size thresholds that may lead to structural failure or operation disruption of point absorbers.
- Assessment of various mitigation strategies to protect point absorbers from ice-ridge-induced damage.

This approach will lead to a better overview of how a point absorber might survive in ice-prone waters. The research will not focus on specific regions or other types of wave energy converters.

1.5 Research question

What are the potential impacts for point absorber-type wave energy converters when colliding with ice ridges?

1.5.1 Sub-research questions

- What are the primary mechanisms and consequences of an interaction between ice ridges and point absorber-type wave energy converters?
- What are the threshold dimensions and characteristics of an ice ridge for a collision between an ice ridge and point absorber to be critical?
- What type of measurements and/or monitoring techniques can be implemented to ensure the resilience of wave energy converters against approaching or colliding ice ridges?
- What are potential design modifications for wave energy converters to enhance their resilience against ice-ridge impacts?

1.6 Research theory and methods

For the research of the mechanisms of the wave energy converter and ice ridge, the most up-to-date literature from resources such as ScienceDirect and ResearchGate will be utilized.

For simulating the collision between the point absorber and an ice ridge, an yet to be determined computational model will be used, which has a possibility of including body-to-body interaction algorithms. The types of computational modeling software that are available is discussed more thoroughly in Chapter 4.4.

1.7 Research structure

The research structure is based on the thesis outline found in Chapter 8. Below the research questions are summed up and in what chapter the questions will be answered.

- Can point absorber-type wave energy converters survive in ice-prone marine environments where ice-ridges are present?

Answered in the model development and conclusion chapter.

- What are the primary mechanisms and consequences of an interaction between ice ridges and point absorber-type wave energy converters?

Answered in the background chapter.

- What are the threshold dimensions and characteristics of an ice ridge for a collision between an ice ridge and point absorber to be critical?

Answered in the sensitivity analysis chapter.

- What type of measurements and monitoring techniques can be implemented to ensure the resilience of wave energy converters against approaching or colliding ice ridges?

Answered in the mitigation measurements chapter.

- What are potential design modifications for wave energy converters to enhance their resilience against ice ridge impacts?

Answered in the mitigation measurements chapter.

2 Literature review

2.1 Literature review methodology

I study the state-of-art because I need an answer to the question: "Can point absorber-type wave energy converters survive in ice-prone marine environments where ice-ridges are present?". For this question I'm going to use relevant literature from ScienceDirect, ResearchGate, Google Scholar and the TU Delft repository.

For this search I need to look for relevant research on a combination of the ice-structure interaction between offshore floating and moored constructions, ice ridges and more specifically the hydrodynamics and ice-structure interaction of point absorbers.

The words that are relevant for the search are:

- "Sea Ice" AND "Wave Energy Converter"
- "Ice ridge" AND "Moored structure"
- "Ice ridge" AND "Floating structure"
- "Ice ridge" AND "Interaction"

The relevant papers/reports/websites need to feature the following elements

- Information regarding ice-structure interaction between ice ridges and moored and/or floating structures.
- Information regarding the ice-structure interactions and/or hydrodynamics of a point absorber or a similar wave energy converter.

Using the insights from these sources, I will set up a research list per relevant study featuring all the main takeaways from the study, including

- Title
- Authors (see references)
- Year of publication (see references)
- Main findings regarding the method and contents

2.2 Literature review

The literature review aims to examine existing studies and information regarding WEC's (and similar structures) and their interactions with ice. This analysis serves as purpose to identify research gaps in the field which will highlight the areas that have not been researched much. So while some of the literature in this review may not directly relate to the thesis assignment, it is nonetheless valuable in mapping out the current state of knowledge in the field.

Since the research one the interaction between WEC's and ice is limited, it was possible to assess a broader range of sources and look at studies that are further away from the main objectives of the thesis than what would be usual done in a graduation assignment. In essence, this literature review serves as a foundation for the graduation assignment, providing a clear picture of what is known and unknown.

The following papers were found to relate the most to the thesis from the literature review, they are explained with their key points outlined underneath.

(1) Full Scale Measurement of Reaction Force Caused by Level Ice Concentration on a Buoy Connected to a Wave Energy Converter. [2]

This study focuses on the first full-scale attempt to measure the vertical reaction on a floating buoy that is connected to a WEC under level ice interaction processes. It delivers information about the forces on floating level ice. Important notes from this study are as follows:

- For project WESA (project related to the ice-structure interaction with a point absorber) the buoy is a hexagonal shaped torus (HSST) which is 6 x 5 m.
- In this study the force equations for level-ice are determined, as well as findings such as that if the value of F_z becomes larger than the value of the buoy force F_b, the buoy begins to go under the ice.

(2) Development of environmental contours for first-year ice ridge statistics. [3]

This study focuses on the development of environmental contours, specifically for first-year sea ice ridge statistics. Key points from this study are as follows:

- Environmental contours are able to represent the key parameters that will influence the extreme loads. It is based on the inverse first order reliability method (IFORM).
- For numerical simulations of ship and ice ridge interaction, the consolidated layer and rubble blocks are usually modelled as solid material (i.e., thick level ice) and granular materials, respectively.
- There are lot's of studies done in the interactions between ice and sloping structures or ships.
- The main advantage of the environmental contour method lies in the fact that the description of the environmental parameters is uncoupled from the structural response obtained from the numerical simulation or experiments.
- The current methodology can be extended for application in connection with reliability-based design of Arctic offshore structures if the key parameters of the ice ridges which govern the interaction process are identified.

(3) An engineering method for simulating dynamic interaction of moored ship with first-year ice ridge. [4]

This study focuses on presenting a tool that simulates the dynamic interaction between the ice ridge and a moored ship in a 6 DoF time-domain. Key points from this study are as follows:

- With this study a tool to simulate dynamic ice ridge-structure interaction in 6 Dofs in time domain is obtained.
- In this study, the consolidated layer is taken as level ice. The related level ice force is simulated by integrating ice breaking force and ice accumulation force.
- The unconsolidated layer is based on a modified theoretical model in probabilistic design.

(4) Application of the contour line method for estimating extreme responses in the mooring lines of a two-body floating wave energy converter. [5]

This study is focused on using the contour line method for estimating extreme response for a two-body floating WEC (the Wavebob in this case) in the mooring lines. The study is not directly related to ice, but to extreme loads and about the tension in the mooring lines.

(5) The effect of environmental contour selection on expected wave energy converter response. [6]

This report compares five environmental contour methods and their consequences on response analysis. The relevant takeaways from this report include that:

- Extreme conditions can be estimated using environmental contours.
- This research does not take into account structural loads.

(6) A literature survey of broken ice-structure interaction modelling methods for ships and offshore platforms. [7]

The focus of this study is not on WEC's but on moored platforms, and specifically the existing methods to model this interaction. It analyses analytical methods, empirical-statistical methods, various computational/numerical methods and hybrid methods. It has the following conclusions:

- Empirical and statistical methods can not accurately model relevant physical processes.
- FEM, PIC, Classic DEM3D, CFD and SPH-methods do not have high numerical efficiency and are often unsuitable when real-time prediction capability is required.
- Hybrid models combine the best of both worlds and are being used more widely for ice-structure interactions.
- Regardless of the method-of-choice, the lack of high-quality physical model tests and full-scale measurements leads to a lower confidence in the validation of the models.

(7) A Moored Arctic Floater in First-Year Sea Ice Ridges. [8]

This study focuses on a model test performed in Hamburg at the Hamburg Ship Model Basin with different ice ridges (different sizes, properties) and a moored conical floater. The findings are mostly about the maximum mooring line forces. The main findings from this study include:

- The study is based on estimating the forces for a so-called Sevan FPU-Ice, which has a diameter of 87 to 103 meter and is moored with 28 mooring lines divided into 4 clusters. The model is scaled to a 1:40 ratio with use of Froude scaling to obtain similarity between inertia and gravity forces. Although the scaled-down dimensions might be similar to the point absorber, the weight and construction of the structure is very different and it can not be compared directly.
- The maximum mooring forces was increasing with the increase of the mean cross-sectional area of the ice ridges.
- Clearance of ice rubble was a dominating process in the interaction between the modeled structure and the ice ridges.
- The calculations from ISO 19906 (older guidelines) had disrepancies from overestimations of 27% of forces to underestimations up to 50%.

2.2.1 What has been researched

The topics that have been researched so far can be summed up as

- The effects of hydrodynamic loading on wave energy converters.
- The effects of level ice on wave energy converters, including full-scale measurements on vertical reaction forces on a floating buoy.
- The effects of ice ridges on heavier moored constructions, such as offshore constructions and ships. Including simulation of dynamic interaction between moored ships and first-year ice ridges, as well as model tests on moored conical floaters in first-year sea ice ridges.
- Development of environmental contours for first-year ice ridges.

2.2.2 What has not been researched

The topic that have not been addressed so far in the literature are

- The effects of ice ridges on wave energy converters, or lighter moored structures in general which potentially will not be able to withstand the forces of ice ridges.
- Long-term performance and survivability of WEC's in ice-prone seas.

- Full-scale testing of the interaction between lighter moored structures or WEC's and first-year ice ridges.

2.3 Research gap

2.3.1 Research gap

The research gap is primarily in what will happen if an ice ridge (of an undetermined size) drifts into a wave energy converter, specifically a point absorber. And what would be the critical threshold size of an ice ridge for the WEC to experience structural failure or operational disruption due to damage or by being submerged. Secondary, the gap can be found in the lack of knowledge on the effect of mitigation strategies on WEC's for the collision itself and for mitigation strategies for preventing a collision.

2.3.2 Research gap questions

What needs to be researched to bridge the research gap can be summed up in the following questions.

- What types of forces will appear to due collisions with ice ridges and how will these forces work on a point absorber-type WEC?
  - How can these forces be modeled?
  - How are the hydrodynamic forces and ice-ridge related forces connected?
- What amount of forces will the point absorber be able to withstand?
  - What will happen with the point absorber upon impact from the ice ridge?
  - What are the threshold values for an ice ridge to do critical damage to a point absorber?
  - When will the wave energy converter be submerged and what are the threshold values for the ice ridge for this to happen?
- What are possible mitigation strategies for wave energy converters against ice ridges?
  - Which mitigation strategies against ice ridges exist in the current literature?
  - How can the known mitigation strategies be applied to wave energy converters?
  - What are ways to prevent structural to the point absorber from an ice ridge?

The research gap questions are converted to the research questions in chapter 1.5.1.

3 Theoretical Framework

3.1 General framework

The main variable where the research is based on is on the development of the model between the WEC and the ice ridge. A simplified theoretical framework graph for the thesis is visible in figure 1.

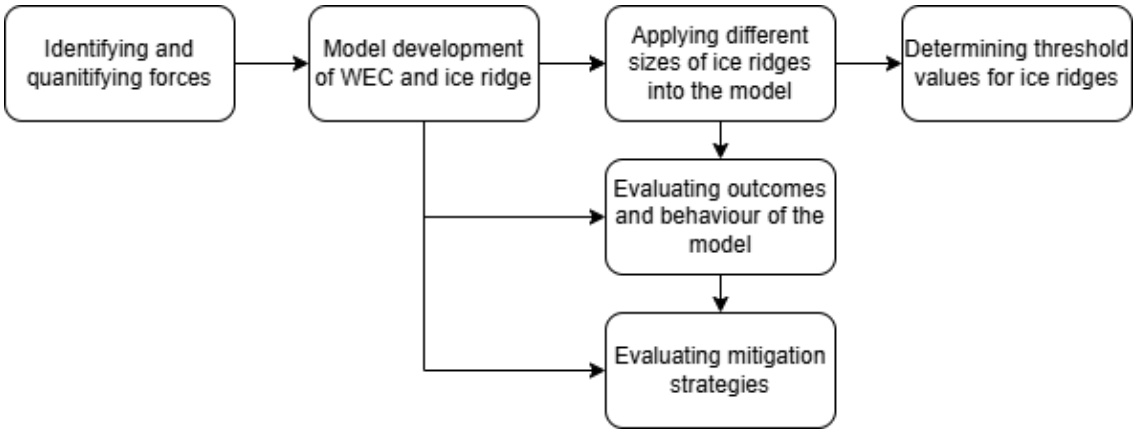
Identifying and quanitifying forces
Model development of WEC and ice ridge
Applying different sizes of ice ridges into the model
Determining threshold values for ice ridges
Evaluating outcomes and behaviour of the model
Evaluating mitigation strategies

Figure 1: Theoretical framework flowchart

This flowchart shows the relations between the different steps and when the steps will be undertaken. The first step is the first objective, which is identifying and quantifying all relevant forces at play for the model. When these are defined the model itself can be developed. During the first step another framework with relevant variables can be set-up.

After the model development there are several ways to go, first of the main objective will be to implement different sizes of ice ridges. However at the same time the results from the first ice ridge can be evaluated as well as the mitigation strategies. These steps are also connected with each other. From the application of different sizes of ice ridges the threshold values for ice ridges (to look at which point a point absorber-type WEC will fail) can also be determined.

4 Research method

4.1 General approach

The general approach is divided into the following steps

1. Summarize the relevant forces/responses (hydrodynamic, structural and ice-induced) that will exist between a collision between a point absorber and an ice ridge and set up the relevant material properties.
2. Start with the modeling approach (see 4.3)
3. Evaluate the results, assess possible mitigation strategies and the risks of point absorbers in ice-prone regions.

4.2 Determining modeling assets

The key to an insightful end-result for this project is to have a realistic approach for the collision between the ice ridge and the wave energy converter. For this certain boundary conditions must be set for the ice ridge and the wave energy converter.

The model can be divided into the following three parts

- The wave energy converter.
- The ice ridge.
- The collision between the wave energy converter and the ice ridge.

4.2.1 The wave energy converter

The wave energy converter itself has been modeled before and thus can be copied from earlier projects and adjusted accordingly. We need a floater that is at least 8 m in diameter and 5 m submerged. The WEC will be a point absorber and has the possibility to be moored (if deemed suitable). The objective of this thesis is not to look at mooring forces, therefore the mooring lines are not necessary if they don't influence the initial behavior, which will be determined later. The point absorber will need to response to the waves. Strength properties of the WEC need to be determined to know when the wave energy converter will fail.

4.2.2 The ice ridge

There are so far no known ice ridges modeled in the modeling software that can be used for wave energy converters. For the first model the dimensions of the ice ridge can be standard (an average ice ridge). The ice ridge needs to float and respond to the waves. The reaction forces caused by level ice interaction of a buoy connected to a wave energy converter have been determined [2]. There are numerous studies done on the forces involved in ice ridges when interacting with structures, however not for the interaction with WEC's, buoy's or lighter structures similar to the one's mentioned before.

4.2.3 The collision

The responses of a two-body collision between the ice ridge and the WEC needs to be modeled. In this scenario an option is to simplify the ice ridge into a rigid object, therefore simplifying the model. Two body interaction algorithms need to be used to model a realistic collision. The details of this collision will be determined later when all the involved forces are known.

4.3 Modeling approach

A simplified idea of the modeling approach is as follows

1. Model the point absorber in 3D, determine the threshold-values for hydrodynamic forces and validate the model.
2. Add the standardized ice-ridge to the model and abstract the hydrodynamic, structural forces and other relevant forces from the model.
3. Set up different sizes of ice-ridges and determine threshold-values.

4.4 Specialist software

The modeling techniques that can be used include finite element modeling (FEM), Particle-in-cell (PIC), Classic Digital elevation models (DEM3D), Computational fluid dynamics (CFD) methods and Smoothed-Particle Hydrodynamics (SPH) methods [7], one note is that these models are not sufficient for real-time prediction capability. However this is not necessary for the desired model. Empirical and statistical models are also considered, but they can not accurately model relevant physical processes [7]. Hybrid models can also be used. It would be desirable if the specialist software itself is open-source and Python-based.

Besides the modeling software, the thesis will be written in Overleaf and Microsoft Office software might be used for presentations (PowerPoint) and calculations (Excel). No other specialist software is required for this thesis.

4.5 Back-up plan

Since the concept of modeling a point absorber (floating object) and an ice ridge (floating object) has not been done before, issues might arise. If the modeling no longer becomes feasible for a graduation thesis, it is important to look at simplifications and alternatives to save time. This can be done by either simplifying the model itself, or using a simpler technique for modeling.

Examples ideas are the following

1. Use of a fixed point absorber, instead of a floating point absorber.
2. Simplification of the ice ridge.
3. Use of equivalent ice-thickness to account for ice ridges (method by Keinonen and Robbins, 1998) in combination with max-to-mean ratios method. (very simplified).

5 Data & Software Management

5.1 Data management

To reach the objectives of this thesis assignment, new information would be created but not necessarily new datasets. Therefore a data management policy is not needed.

5.2 Software management

The software-of-choice for modeling is explained in chapter 5.3. And as stated previously in chapter 4.4, the only specialist software that will be used besides the modeling software are Microsoft Office packages, which are available through Delft University of Technology.

5.3 Software options for modeling

As stated before in chapter 4.4, there are several modeling techniques that can be used to develop the model. An example of range of open-source software for wave energy converters that can be used to model the interaction includes, but is not limited to the following programs:

- DualSPHysics
- WEC-Sim
- OpenFOAM

Which are explained shortly below, note that the final software-of-choice to model the interaction might not be included in this list. The aim is to make use of open-source software and therefore accesibility information is not required.

DualSPHysics

DualSPHysics is based on the Smoothed Particle Hydrodynamics model named SPHysics. It is a set of C++ and CUDA codes designed to deal with real-life engineering problems. It includes the discrete element method coupled with SPH. There are several examples of this software being used for wave energy converters. It can be coupled with PROJECTCHRONO to simulate fluid solid interaction phenomena.

WEC-Sim

WEC-Sim is a wave energy converter simulator, which is open-source software, to simulate wave energy converters. The software is developed in MATLAB/SIMULINK using the multi-body dynamics solver Simscape Multibody. The software can be used for various scenarios for wave energy converters.

OpenFOAM

OpenFOAM, short for open-source Field Operation and Manipulation is a computational fluid dynamics (CFD) toolbox that can be adapted for simulating ice-structure interactions. OpenFOAM can be customized to simulate the interacton between ice ridges and WECs by implementing appropriate ice mechanics models and coupling them with existing wave and structure solvers.

6 Societal Impact

The research on point absorbers in ice-prone regions presents some ethical considerations. This analysis will focus on the key stakeholders, potential impacts and the ethical implications of the research methodology.

6.1 Stakeholders and impacts

The primary stakeholders for this research are as follows:

1. Governmental organizations responsible for determining locations for wave energy projects
2. Energy companies
3. WEC developers, specifically developers of point absorbers
4. Delft University of Technology

The first-order impacts would include improved information about wave energy converters in ice-prone regions. This is especially important for the first 2 main stakeholders. Besides this there would be an improvement on the current knowledge which WEC developers and the university can build on. Second-order impacts include potential shifts in planning to build wave energy converters in ice-prone regions.

6.2 Values and legal considerations

Another point to consider is the legal backdrop of the research. There are no laws and regulations to adhere by during the research, and since there is no company outside of the university involved during this research there is no expected legal backdrop.

6.3 Ethical reflections

This research aims to expand the knowledge on the use of wave energy converters in ice-prone regions, which aligns with the ethical principle of beneficence by potentially improving energy access. The research does not take into account the environmental harm that could be done by wave energy converters in ice-prone regions, since that is unrelated to the work. Since the research also does not involve any sensitive data, there are no ethical risks in this regard.

7 Safety Risks

In the risk-mitigation Table 1 below the safety risks are outlined, including the potential cause and issue and mitigation strategies.

Table 1: Risk mitigation table

	Risk description	**Potential cause and issue**	**Mitigation strategy**
1	Research is delayed	Adjustment of topic, availability of supervisors or personal reasons (including sickness).	Reschedule of final presentation dates.
2	Oversimplification or over-complication of the model	Inaccurate predictions or computationally intensive model	Regular validation, sensitivity analysis for key parameters or dimensionality reduction strategies.
3	Scope creep	The scope may expand beyond the original plan if deemed necessary, leading to time constraints	Recheck scope and adjust accordingly for the available time. Also make sure of clearly defined objectives.
4	Dependance on assistance/resources	Reliance on feedback from others might lead to time constraints or delays	Plan well ahead for potential assistance.
5	Final deliverable quality	The quality of the results might be lacking academically	Expand the scope
6	Software/hardware limitations	Insufficient computational resources	Simplification of the model, make use of cloud computing services or code optimization for efficiency
7	Programming issues	Programming becomes too advanced to continue	Simplication of the model, make use of experts at TU Delft
8	Limited validation options	Due to the limited amount of research on the topic, validation will be difficult	Don't focus on numerical results, but rather on behavioural outcomes.

The probability of these risks to happen is for most of them low to medium. However the programming and software related issues can occur and there is a need to be continuously aware of this. The other risks such as scope creep and a lower final deliverable quality is lower and can be avoided by regular control of the work done so far and if it's still relevant and within the scope.

8 Outline of the thesis

The outline of the thesis will be similar to the following outline, this outline excludes the typical chapters such as the abstract and the references. This outline is not definite and might chance during the thesis but gives a general representation of the involved chapters.

- **Introduction**
  - Problem description as well as typical introductory points such as motivation and a short summary.
- **Background (working title)**
  - The wave energy converter: which WEC is chosen and what are it's properties.
  - The ice ridge: how do ice-ridges work and what are the properties of the chosen ice ridge.
  - Collision: what are the involved forces and phenomena when an ice ridge collides with a wave energy converter.
- **Methodology**
  - Approach to the modeling of the point absorber WEC.
  - Approach to the modeling of the ice ridge.
  - Approach to the modeling of the collision.
- **Model development**
  - The results of the model
- **Sensitivity analysis**
  - Results of the sensitivity analysis, showing the detrmined threshold-values for ice ridges.
- **Mitigation measurements**
  - Assessment of possible mitigation measurements
- **Conclusion**
  - Summary of all the results
  - Recommendations for further research
  - Implications for existing knowledge

9 Expected output

9.1 Expected thesis insights

The thesis aims to deliver insights into the following topics:

- A breakdown of the primary forces at play during an interaction between a point absorber-type WEC and an ice ridge, including hydrodynamic forces, ice-induced forces and structural response forces.
- Critical threshold values for the size of ice ridges that pose significant risks to point absorber-type WEC's.
- An evaluation of various protective measurements and/or mitigation strategies for point absorbers against ice ridges.
- Further research directions in suggestions for areas of further study to better improve the knowledge on the risks of deploying wave energy farms in ice-prone regions.

9.2 Expected tool-output

The expected tool-output for the thesis is a 3D-model that can be used to simulate the interaction or collision between a point-absorber type wave energy and an ice ridge, which can be adjusted in size.

10 Time planning

10.1 General planning

This thesis project is worth 30 ECTS, accounting to 21 full-time work weeks. The planning needs to account for the following:

- Final deadline of the thesis
- Holidays
- Feedback moments, committee meetings

The thesis is expected to start after the Christmas break. If this were to be on the 20th of January, accounting for 1 week of holiday break, the thesis needs to be finished around the 23rd of June. A month prior to that date the aim is to already have the thesis delivered for final remarks. This would be around the 12th of May.

However this does not include unexpected delays due to personal reasons, which can always occur.

10.2 Planning based on chapters

The time planning for the thesis itself is based on the outline of the thesis, per chapter

- Introduction
- Background
- Methodology
- Model development
- Sensitivity analysis
- Mitigation measurements
- Conclusion

Per chapter the expected starting time would be as seen in Table 2, where it can be noted that in week 17 most of the study should be finished already and only the details are for the last 4 weeks.

Chapter	**Expected starting time**
Introduction	Week 1
Background	Week 1
Methodology	Week 3
Model development	Week 5
Sensitivity analysis	Week 13
Mitigation measurements	Week 15
Conclusion	Week 13

Table 2: Expected duration per chapter

References

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